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CyberKM: harnessing dynamic knowledge for competitive advantage through cyberspace

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CyberKM: Harnessing Dynamic Knowledge for Competitive Advantage through Cyberspace

by

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ABSTRACT

Knowledge is key to sustainable competitive advantage, but different kinds of knowledge affect competitive advantage differently, and they exhibit qualitatively different dynamic properties and behaviors. This places particular importance on understanding the dynamics of knowledge as it flows from where and when it is to where and when it is needed. Given the increasingly strategic importance of computer networks in terms of achieving, defending and ultimately sustaining competitive advantage, understanding how to manage dynamic knowledge through Cyberspace has become critical to organizational survival. Unfortunately, considerable confusion and uncertainty regarding Cyberspace knowledge management (CyberKM) abound and persist, rendering pursuits of sustainable competitive advantage daunting at best and infeasible in many cases. The research described in this paper builds upon Knowledge Flow Theory to illustrate a scheme for measuring dynamic knowledge flows in the cyber domain. Through this novel approach to measurement, one can analyze and visualize the relative power, speed and proliferation of both tacit and explicit knowledge through organizations, which enables knowledge leaders, managers and workers to understand the comparative costs and benefits of alternate approaches to and technologies for managing cyber knowledge. This work articulates a clear set of tradeoffs facing decision makers in Cyberspace, and it provides principles-based techniques for making cyber knowledge decisions in a rational and informed manner. Hence we offer a theoretical contribution suitable for academic journals, but we highlight in particular current, practical application through enhanced decision making in the context of harnessing dynamic knowledge for sustainable competitive advantage through Cyberspace.

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I. INTRODUCTION

Knowledge is key to competitive advantage (Cole, 1998; Grant, 1996; Spender, 1996). Knowledge enables effective action; effective action drives superior performance; and superior performance supports competitive advantage (Nissen, 2006, ch. 1). Indeed, some scholars (Drucker, 1995) argue that knowledge represents the only sustainable source of competitive advantage. However, knowledge does not represent a single, monolithic concept (Nissen & Jennex, 2005). Different kinds of knowledge (e.g., tacit, explicit, individual, group, created, applied) have qualitatively different properties and behaviors and hence affect action, performance and competitive advantage differently (Nissen, 2005).

In particular, although explicit knowledge (Nonaka, 1994) can provide a basis for competitive advantage (Grant, 1996), such advantage is likely to be ephemeral. Unless explicit knowledge can be kept secret, competitors are likely to acquire it, to imitate the knowledge-based actions that enable performance superiority, and hence eliminate any competitive advantage based upon such knowledge (Dierickx, Cool, & Barney, 1989). Alternatively, tacit knowledge is more appropriable than explicit knowledge is; hence the knowledge-based actions that it enables are more difficult for competitors to imitate. Speaking generally, the more tacit that knowledge becomes, the greater its competitive potential becomes (Saviotti, 1998).

This places particular importance on understanding the dynamics of knowledge as it flows from where and when it is to where and when it is needed. Although dynamic, knowledge is distributed unevenly through the enterprise. It moves, clumps and accumulates noticeably within specific people (e.g., experts), organizations (e.g., R&D units), locations (e.g., headquarters) and times of application (e.g., shift changes). Capitalizing on this dynamic resource for enterprise performance and hence competitive advantage depends upon its rapid and reliable flows across such people, organizations, locations and times.

Given the increasingly strategic importance of computer networks in terms of achieving, defending and ultimately sustaining competitive advantage, understanding how to manage dynamic knowledge through Cyberspace has become critical to organizational survival. Business-to-business and business-to-consumer electronic commerce (Schneider, 2009), network-centric warfare and operations (Cebrowski & Garstka, 1998), computer network defense, exploitation and attack (Wilson, 2007), and myriad other, critical, network endeavors seek competitive advantage through Cyberspace.

Unfortunately, considerable confusion and uncertainty regarding Cyberspace knowledge management (CyberKM) abound and persist, rendering pursuits of sustainable competitive advantage daunting at best and infeasible in many cases. The term *Cyberspace*, for instance, ranges in definition from fictitious network presence (Gibson, 1984) to the focus of a major US Military command (McMichael, 2010), and debates continue on the extent to which cyber should be viewed as a domain (e.g., like air, space, sea or land) or a weapon (e.g., like airplanes, satellites, ships and tanks) to achieve objectives (Koons, Bekatoros, & Nissen, 2008). Knowledge management (KM), as a related instance, addresses knowledge across the spectrum from tacit to explicit, but the focus of KM related to computer networks is predominately on explicit knowledge, information and data, relegating it to a supportive role (Nissen, Kamel, & Sengupta, 2000). The complementary tacit knowledge—which is arguably much more powerful (Lee & Nissen, 2010)—resides within the minds of the people and routines of the organizations that use such networks (Nissen, 2008). Hence CyberKM practice is beginning with a bias toward less-powerful forms of knowledge, forms which are inadequate to support the kinds of sustainable competitive advantage discussed above (Dierickx et al., 1989; Saviotti, 1998).

The research described in this paper builds upon Knowledge Flow Theory (Nissen, 2006) to illustrate a scheme for measuring dynamic knowledge flows in the cyber domain. Through this novel approach to measurement, one can analyze and visualize the relative power, speed and proliferation of both tacit and explicit knowledge through organizations, which enables knowledge leaders, managers and workers to understand the comparative costs and benefits of alternate approaches to and technologies for managing cyber knowledge. This work articulates a clear set of tradeoffs facing decision makers in Cyberspace, and it provides principles-based techniques for making cyber knowledge decisions in a rational and informed manner. Hence we offer a theoretical contribution suitable for academic journals, but we highlight in particular current, practical application through enhanced decision making in the context of harnessing dynamic knowledge for sustainable competitive advantage through Cyberspace.

The balance of this paper begins with background information on Knowledge Flow Theory and continues with an overview of this measurement scheme. We then incorporate numerical examples of knowledge flow measurement pertaining to Cyberspace and explain how they contribute to enhance decision making. The paper concludes with key findings, implications and future research directions.

II. BACKGROUND

Nissen (Nissen, 2005) describes the concept *knowledge flows* in terms of dynamic knowledge and indicates that it subsumes similar concepts such as *knowledge conversion, transfer, sharing, integration, reuse* and others that depict changes, movements and applications of knowledge over time. Knowledge Flow Theory (Nissen, 2006) describes the dynamics of knowledge flows phenomenologically, and it includes multidimensional, analytical and graphical techniques for understanding, interpreting and comparing a diversity of flows. Drawing directly from Nissen (2007), we organize this brief overview of Knowledge Flow Theory into four parts: 1) knowledge uniqueness, 2) knowledge flows, 3) knowledge dimensions and visualization, and 4) knowledge flow analysis. Interested readers are directed to Nissen (2006) for details.

A. KNOWLEDGE UNIQUENESS

In this characterization, *knowledge* is conceptually distinct from *information, data* and *signals*: knowledge enables effective action (e.g., decisions, behaviors, work); information provides meaning and context for action (e.g., decision criteria, behavioral stimuli, work settings); data answer context-specific questions (e.g., How much profit is expected by selecting Alternative A? Who says that we should honor our commitments to the workers? How many industrial accidents have occurred so far this year?); and signals transmit detectable events across physical space (e.g., light patterns from pages in a book, sound waves from voices in a room, voltage differences across cables in a computer network).

Many scholars (Davenport & Prusak, 1998; Nissen et al., 2000; von Krogh, Ichijo, & Nonaka, 2000) conceptualize a hierarchy of knowledge, information, and data. As illustrated in Figure 1, each level of the hierarchy builds upon the one below. For example, data are required to produce information, but information involves more than just data (e.g., need to have the data in context). Similarly, information is required to produce knowledge, but knowledge involves more than just information (e.g., it enables action). We operationalize the irregular shape of this hierarchy using two dimensions—*abundance* and *actionability*—to differentiate among the three constructs.

Briefly, data lie at the bottom level, with information in the middle and knowledge at the top. The broad base of the triangle reflects the abundance of data, with exponentially less information available than data and even fewer chunks of knowledge in any particular domain. Thus, the width of the shape at each level reflects decreasing abundance in the progress from data to knowledge. The height of the shape at each level reflects actionability (i.e., the ability to take appropriate action, such as informed decisions, appropriate behaviors or productive work). Converse to their abundance, data are not particularly powerful for supporting action, and information is more powerful than data are, but knowledge supports action directly, hence its position at the top[1] of the shape.

[1] Notice that we exclude any constructs "above" *knowledge*. *Wisdom, enlightenment, omniscience* and like constructs all reduce to enabling different kinds of actions, which *is* knowledge in this conceptualization.

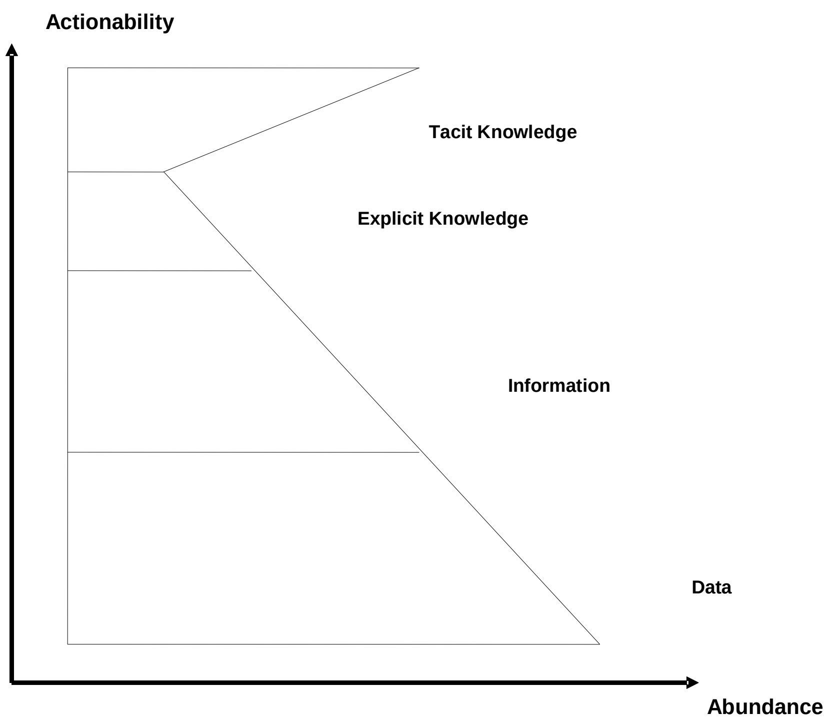

Figure 1 Knowledge Hierarchy (adapted from Nissen, 2006)

Notice that we position tacit knowledge "above" its explicit counterpart in this figure. Tacit knowledge is characterized widely as being very rich in terms of enabling action, whereas explicit knowledge represents often a diluted formalization of its tacit counterpart, with many properties and behaviors that are similar to those of information (Nissen, 2005). Further, unlike explicit knowledge, which must by definition be formalized, articulated or otherwise made explicit (e.g., via books, graphs, charts, software), and hence is somewhat limited in abundance, tacit knowledge accumulates naturally (e.g., through direct experiences and observations of people), and is quite abundant. This is the basis for the irregular shape depicted in the figure.

B. KNOWLEDGE FLOWS

In terms of knowledge flows (e.g., movements of knowledge across people, organizations, places and times, from where and when it is to where and when it needs to be), the two connected knowledge hierarchies depicted in Figure 2 illustrate some key concepts. On the left side, we see a knowledge producer's or source's knowledge hierarchy, and on the right side, we see a knowledge consumer's or receiver's hierarchy. Both of these knowledge hierarchies conform to the characterization above (e.g., abundance vs. actionability, layers building upon one another, distinct concepts, irregular shape). The producer hierarchy includes an arrow pointed downward (i.e., from knowledge, through information, to data), and the consumer hierarchy includes an arrow pointed upward. This depicts the relative direction of knowledge as it flows from producer to consumer.

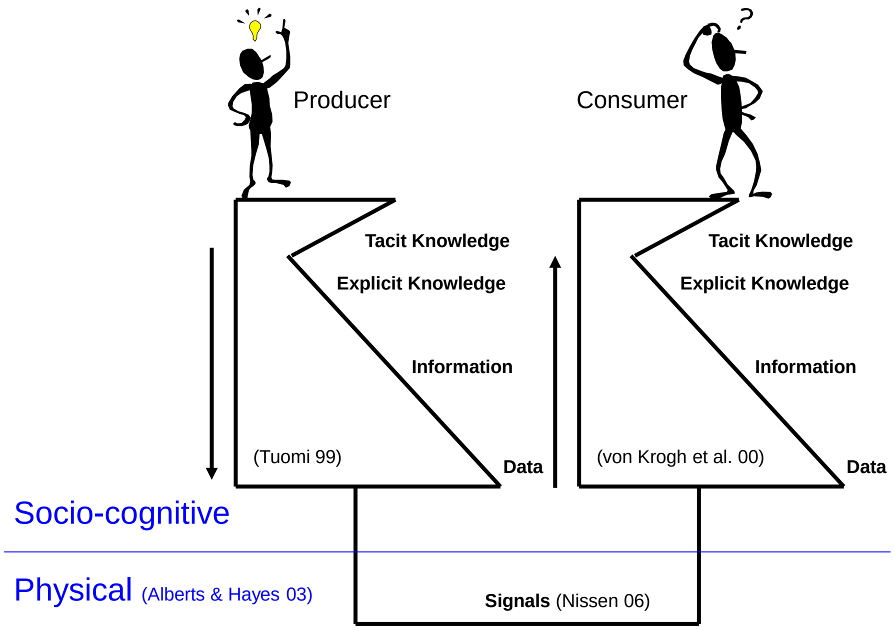

Figure 2 Knowledge Flows (adapted from Nissen, 2006)

Specifically, following Tuomi (1999), the producer utilizes existing knowledge to create information, which is used in turn to produce data, which are transmitted via signals across some physical space. Then, following von Krogh et al. (2000), the consumer interprets the data from signals, develops information through incorporation of meaning and context, and finally develops actionable knowledge through some learning mechanism. Of course, the directionality of arrows can reverse (i.e., a "producer" can become a "consumer," and vice versa), and multiple knowledge hierarchies can participate simultaneously, but this provides a phenomenological description of how knowledge flows. Notice that only signals are involved with flows across physical space; following Alberts and Hayes (2003), flows of data, information and knowledge take place in the socio-cognitive domain.

C. KNOWLEDGE DIMENSIONS AND VISUALIZATION

Figure 3 depicts a multidimensional space to visualize dynamic knowledge flows. Briefly, the vertical axis represents the dimension *explicitness*, which characterizes the degree to which knowledge has been articulated in explicit form. This dimension draws from the Spiral Model (Nonaka, 1994) and includes a binary contrast between tacit and explicit knowledge. The horizontal axis represents the dimension *reach*, which characterizes the level of social aggregation associated with knowledge flows. This dimension draws from the Spiral Model also and includes several ordinal categories of social aggregation (e.g., individual, group, organization). The third axis represents the dimension *life cycle*, which characterizes the kind of activity associated with knowledge flows. This dimension represents an extension to the Spiral Model (Nissen, 2002) and includes several nominal categories of life cycle activity (e.g., create, share, apply).

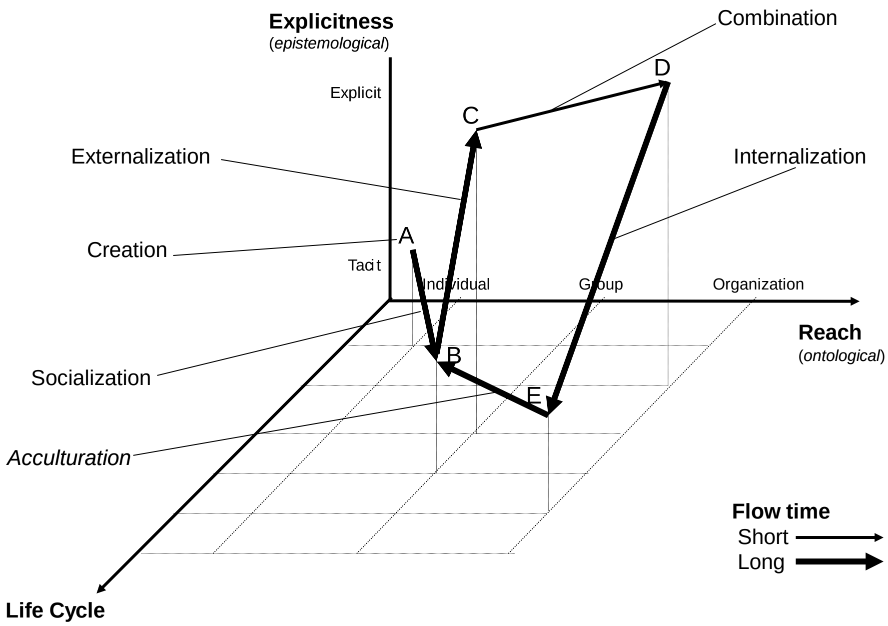

Figure 3 Multidimensional Knowledge flow Visualization (adapted from Nissen, 2006)

Together, these axes combine to form a three-dimensional space. We include the fourth dimension *flow time*, which pertains to the length of time required for knowledge to move from one coordinate point in this three-dimensional space to another. This dimension represents an extension to the Spiral Model also and includes a binary contrast between relatively long (i.e., slow) and short (i.e., fast) knowledge flows. Because visualization in four dimensions does not come naturally to most people, we use arrows of different thickness (e.g., thick for slow flows, thin for fast flows) when delineating various knowledge flow vectors.

For instance in the figure, these four dimensions are used to visualize the kinds of patterns associated with the Spiral Model. Each vector in this loop corresponds to one of four knowledge flow processes articulated in the model (i.e., *socialization, externalization, combination, internalization*). We begin at Point A, representing tacit knowledge created (i.e., learned) by an individual. The socialization flow (A-B) reflects a movement of tacit knowledge across the reach dimension to the group level. The externalization flow (B-C) reflects a movement from tacit to explicit knowledge at this group level. The combination flow (C-D) reflects in turn a movement of explicit knowledge across the reach dimension to the organization level. In terms of flow time, notice that we use a thinner arrow to represent this combination flow, as only explicit knowledge—which is not as "sticky" as tacit knowledge is (Nissen et al., 2000; Nissen et al., 2000; von Hippel, 1994)—is involved. Penultimately, the internalization flow (D-E) reflects a movement from explicit to tacit knowledge at this organization level. Finally, we include a (reverse) socialization flow entitled "acculturation" from Points E to B (i.e., tacit knowledge moving from the organization to the group level) to complete the one loop. Clearly, myriad other knowledge flows can be represented in this manner, but this single loop is representative of the technique, and it provides an illustration of how the four knowledge dimensions can be integrated into a single figure for flow visualization.

D. KNOWLEDGE FLOW ANALYSIS

Finally, knowledge flow analysis utilizes the multidimensional visualization space from above. To re-iterate, *knowledge* does not represent a single, monolithic concept. Different kinds of knowledge (e.g., in various parts of the multidimensional knowledge flow space) have different properties and behaviors. Indeed, one can identify at least 96 (2 levels of *explicitness* x 4 levels of *reach* x 6 levels of *life cycle* x 2 levels of *flow time*) theoretically distinct kinds of knowledge, each potentially with its own, unique set of properties and behaviors. Hence the position of a particular knowledge flow within this multidimensional space would appear to be important, and such position can be used for knowledge flow analysis.

For instance, notice that all but one of the knowledge flow vectors represented in Figure 3 are depicted using relatively thick lines to designate long flow times (i.e., slow flows) and that all such vectors involve flows of tacit knowledge. Drawing from knowledge flow principles (Nissen, 2006), we understand that "sticky," tacit knowledge flows relatively slowly and that such flows are constrained generally to individuals, dyads and small groups. Take, for example, the kind of trial-and-error learning associated generally with experience-based knowledge; it takes people years, and even decades, to master certain domains via experience, and learning such experience-based, tacit knowledge represents largely an individual endeavor.

However, as noted above, tacit knowledge is very rich in terms of enabling action, with many actions (e.g., riding a bicycle, negotiating a contract, conducting qualitative research) dependent upon experience-based tacit knowledge for effective performance. Hence tacit knowledge flows tend to be limited to a specific portion of the multidimensional space depicted above (i.e., the tacit end of *explicitness*, the individual range of *reach*, and the long end of *flow time*), but they are rich in terms of enabling action. Alternatively, explicit knowledge flows have contrasting, dynamic properties and behaviors: they flow relatively quickly and broadly, yet become diluted, and are limited in terms of enabling action (e.g., consider attempting to ride a bicycle, negotiate a contract, or conduct qualitative research based *solely* upon reading a book about the subject; i.e., with no direct experience to develop tacit knowledge).

If one is interested in moving knowledge from one part of the multidimensional space to another (e.g., across people, organizations, places and times, from where and when it is to where and when it needs to be), then one has multiple possible paths for the corresponding knowledge flows to follow. Consider the multidimensional knowledge flow space depicted in Figure 4. Say that some individual creates new, tacit knowledge (e.g., how to accomplish some useful action) and that the organization is interested in such new knowledge being applied, quickly, organization-wide, say by 100 people who are separated across both time and space in a virtual organization. In the figure, such knowledge would have to flow from Point A to Point B. Consider, however, that such path may be infeasible: the organization may not have a process that enables such tacit knowledge to flow—quickly and directly—from an individual to 100 geographically and temporally distributed people. This is depicted in the figure by the symbol "RIDGE" that blocks such a direct flow.

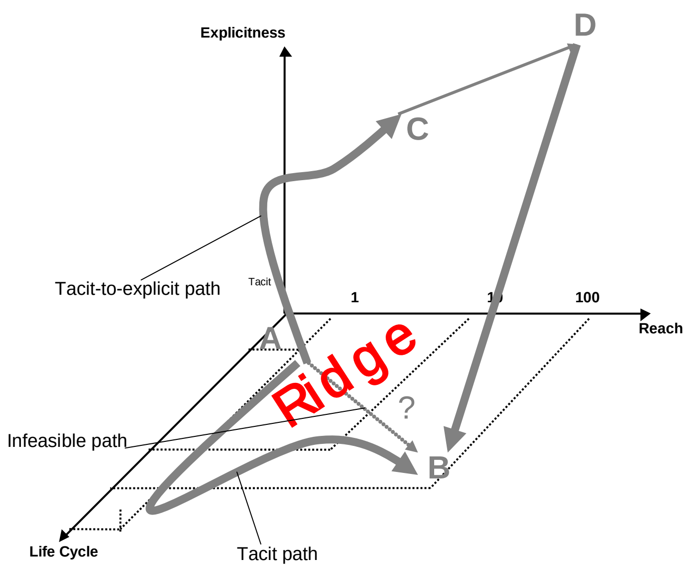

Figure 4 Best Knowledge Flow Path Analysis (adapted from Nissen, 2006)

Instead, we illustrate two, alternate flow paths that the organization could consider. One reflects a thick, curved path that stays within the tacit plane, and which appears to go around the ridge (labeled "Tacit path"). Remaining within the tacit plane as such, this knowledge flow would be relatively slow, but it would retain its richness in terms of enabling action. The corresponding organizational processes could include a series along the lines of: the individual learns (e.g., via trial and error) to apply the new knowledge; then shares such tacit knowledge (e.g., via mentoring) with a small group of colleagues; who participate in turn to mentor other small groups (e.g., in various communities of practice).

Alternatively, the organization could choose instead to formalize the tacit knowledge (e.g., in terms of a classroom course). This formalization is represented by Point C and is depicted by a relatively thick vector (labeled "tacit-to-explicit path") to indicate slow knowledge flow (e.g., known well through abundant knowledge-formalization research in artificial intelligence), which appears to go over the ridge.

Nonetheless, at this point above the tacit plane, the formalized knowledge has been made explicit and hence can be shared broadly and quickly with many people in the organization (e.g., taking the course). This is represented by Point D and is depicted by a relatively thin vector to indicate fast knowledge flow.

Still, people taking the course would need to internalize the knowledge, and to have it become tacit, before being able to apply it effectively at Point B. Noting the relatively thick arrow depicting the corresponding knowledge flow vector, such internalization represents a relatively slow process (e.g., few people emerge from a formal training course as "masters" of the subject studied). Moreover, some question remains as to whether this knowledge—even after being internalized and applied as such—would retain the same degree of action-enabling richness as that flowing along the other path (i.e., within the tacit plane).

Hence one can trade off the relative speed, breadth and dilution of knowledge flowing along this latter, tacit-to-explicit path against the comparatively slow and narrow but rich knowledge flows within the tacit plane. Of course, many other, alternate paths are possible too, and each pair of coordinate points within this multidimensional space offers its own unique set of alternate paths and corresponding tradeoffs. The key is, we have the ability to characterize and visualize a diversity of knowledge flows—taking account of the different, dynamic properties and behaviors corresponding to various positions within the multidimensional space—and we have a graphical and analytical technique to compare alternate knowledge flows in the organization. This provides a basis for extending Knowledge Flow Theory to incorporate measurement of such dynamic knowledge flows.

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III. KNOWLEDGE FLOW MEASUREMENT

In this section, we build upon and extend Knowledge Flow Theory to articulate a novel scheme for measuring dynamic knowledge flows. Such conceptualization centers on how to operationalize measurement constructs for the four dimensions discussed via the model above. Some of these dimensions appear to lend themselves toward operationalization more than others do. *Flow time*, for instance, is defined in terms that suggest straight forward measurement: the length of time required for knowledge to flow from one coordinate point to another. Although we introduce a simple, binary contrast between fast and slow flows in the discussion above, *flow time* lends itself to immediate measurement, as one can use a watch or calendar to measure elapsed time directly (e.g., via a ratio scale).

Table 1 Dimensions & Operationalizations

Dimension	Operationalization
Flow time	Time for knowledge to flow between coordinates
Reach	Number of people in social unit
Explicitness	Unclear
Life cycle	Unclear
Power	Influence on competitive advantage

Reach, as another instance, is defined in terms that enable measurement as well: the level of social aggregation associated with knowledge flows. Although we introduce a simple, ordinal set to differentiate between individual, group and organizational levels of reach in the discussion above, *reach* lends itself to measurement too, as one can count the number of people in a group or organization who possess particular knowledge to measure social aggregation (e.g., via a ratio scale).

Alternatively, operationalization of the other dimensions is more challenging. *Explicitness*, for instance, is characterized in the discussion above as a simple, binary contrast between tacit and explicit knowledge. Although we represent this dimension as a continuum between tacit and explicit endpoints, which suggests that measurement of varying levels of explicitness are possible, we remain unaware of an effective technique for measuring such levels. At this point we must leave operationalization and measurement of the explicitness dimension to future research.

Life cycle, as another instance, is characterized in the discussion above as a categorical set to differentiate between creation, sharing, application and other kinds of activity associated with knowledge flows, but it is unclear how to characterize such dimension in a manner lending itself to measurement (i.e., other than this simple, nominal scale). At this point we must leave operationalization and measurement of the life cycle dimension to future research also.

Finally, we know from Knowledge Flow Theory and its underlying base of research and literature that tacit knowledge is inherently richer and more powerful than its explicit counterpart is. Referring to explicit knowledge using terms such as *diluted*, for instance, and explaining how tacit knowledge can enable *sustainable* competitive advantage, as another instance, the comparative power of tacit versus explicit knowledge is qualitatively different. Our general approach to operationalizing *power* for measurement is by linking it to organizational performance, and we characterize power further as the direct influence that knowledge has on competitive advantage.

As reflected in Table 1, to summarize the scheme above, we have two model dimensions (i.e., *flow time* and *reach*) that lend themselves to immediate operationalization and measurement (e.g., using a watch or calendar to measure elapsed time, counting the number of people in a group or organization who possess particular knowledge to measure social aggregation) and two (i.e., *explicitness* and *life cycle*) that remain challenges in terms of operationalization. We have the new attribute *power* also, which we can operationalize by linking it to organizational performance (e.g., the direct influence that knowledge has on competitive advantage).

IV. CYBERSPACE APPLICATION

In this section, we continue the work summarized above to discuss how Cyberspace application of the model and measurement scheme can be employed in a decision making context. We begin with some important definitions and assumptions and then continue with a series of numerical examples.

A. DEFINITIONS AND ASSUMPTIONS

As noted and summarized in Table 1 above, we have three dimensions that offer opportunities for immediate operationalization and measurement: *flow time*, *reach* and *power*. Since we lack empirical measurements for these dimensions at present—indeed empirical measurement represents a fruitful avenue to extend this line of research—for this practical illustration we make some assumptions regarding each dimension here, then we assess the sensitivity of such results subsequently.

Beginning with flow time, we understand how tacit knowledge flows much more slowly than explicit knowledge does—this effect appears to be especially pronounced in the cyber domain—but we need some means to assess the relative speeds of such flows. For purposes of this paper, we begin with an assumption that an order of magnitude contrasts the relative flow times in Cyberspace; accordingly, tacit knowledge would flow ten times more slowly than explicit knowledge would. Follow-on research to assess the relative flow times of tacit and explicit knowledge across a diversity of operational organizations in practice would appear to be relatively straightforward (e.g., using a watch or calendar to measure elapsed time).

In terms of reach, it is clear that the sizes of different groups and organizations can vary greatly, both in terms of the total number of people involved and the extent to which knowledge flows can permeate throughout such people. For purposes of this paper, we continue with an assumption that a group is comprised of ten people and that an organization is comprised of ten, equally sized groups; accordingly, group knowledge would reach ten times as many people as individual knowledge would, and organizational knowledge would reach 100 times (10 people x 10 groups) as many. Follow-on research to assess the relative reach of tacit and explicit knowledge across a diversity of operational organizations in practice would appear to be relatively straightforward also (e.g., counting the number of people in a group or organization who possess particular knowledge to measure social aggregation).

In terms of power, we understand how tacit knowledge is inherently richer and more powerful than its explicit counterpart is. This is arguably highly pronounced in the cyber domain. Consider the difference in response time and efficacy when comparing the performance of a highly experienced person (i.e., relying predominately upon tacit knowledge) responding to a sophisticated cyber attack with that of a relative novice equipped with documents, procedures and like written materials (i.e., relying predominately upon explicit knowledge). Where such attack is relatively novel and severe (e.g., launched by professional attackers), extant explicit knowledge may prove to be inadequate to mount an effective defense, hence making the experience-based tacit knowledge indispensible. Alternatively, where such attack reflects a familiar pattern and is more innocuous (e.g., launched by amateur hackers), extant explicit knowledge may prove to be more than adequate to mount an effective defense, hence rendering the experience-based tacit knowledge unnecessary. Hence, rich, experience-based tacit knowledge can be viewed as more powerful than its explicit counterpart in terms of supporting appropriate cyber action, but the full power available through such tacit knowledge may not be required in a particular situation.

Table 2 Dimensions & Assumptions

Dimension	Assumption
Flow time	Tacit knowledge flows 10x more slowly than explicit
Reach	10 people per group, 10 groups or 100 people per org
Explicitness	n/a
Life cycle	n/a
Power	Tacit knowledge has 10x the power of explicit

To reflect this characterization, we include a similar, order-of-magnitude assumption regarding the relative power of tacit and explicit knowledge; accordingly, tacit knowledge flows would have ten times the power that explicit flows would. Table 2 summarizes this assumption set. As noted above, through the numerical examples below, we can examine the sensitivity of these assumptions.

B. CYBERSPACE EXAMPLES

Using the model and assumptions described above, we simulate and measure the dynamics of alternate knowledge flows across a series of Cyberspace examples. In each example, we consider arbitrary time units (e.g., days, weeks, months) and focus solely on the *relative dynamics* of tacit versus explicit knowledge flows. In each example and as depicted via Figure 4, we begin with tacit knowledge created at the individual level.

For instance, say that some individual in a cyber organization comes up with an effective technique—requiring considerable judgment and finesse—for responding to a novel type of network attack with an immediate and effective counterattack. This lone individual cannot be everywhere in the organization at once, obviously, and hence cannot counter every attack along these lines that is experienced by the organization. Say further that the kinds of judgment and finesse required to counterattack effectively do not lend themselves to explicit articulation; that is, like success at negotiating contracts, leading people, playing chess, and other, knowledge-based activities requiring considerable judgment and finesse, simply reading a book or like explicit document on how to do it well is not the same as developing the tacit skill. The organization is clearly interested in inducing the corresponding tacit knowledge to flow.

Because this individual's knowledge is tacit, it flows with power 10 based on our table above. In terms of the cyber domain, power 10 could signify disabling one of an adversary's network attack nodes, disabling an adversary's network attack capability for one hour, or some similar measure of effectiveness pertinent to this domain. For simplicity we assume that such power level remains constant over time (i.e., the individual does not learn further *regarding this particular chunk of knowledge*; such individual could, however, learn and hence share *other knowledge chunks*) and that the individual is both motivated and encouraged to share such knowledge with other people in the group and organization.

Further, in each example, we compare the dynamics of two, alternate approaches to knowledge flows: 1) tacit knowledge flows are associated with the kinds of socialization process discussed in terms of the Spiral Model above, where, for instance, an individual embeds him or herself in a group and through dialog, observation, explanation and other techniques such as mentoring and apprenticeship helps the other group members to learn the corresponding knowledge; and 2) explicit knowledge flows are associated with the kinds of externalization and combination processes discussed in terms of the Spiral Model above, where, for instance, an individual formalizes his or her knowledge through some means of articulation such as written, multimedia documents and distributes this explicit knowledge through electronic means such as an intranet web portal with document repository and search capabilities. In each example, we simulate and compare the relative knowledge flow time, reach and power associated with these two techniques.

1. Baseline Example

Table 3 summarizes the simulated results for the initial condition at Time 0 and the subsequent ten time steps. The first column includes the time steps. The next three columns show the *knowledge power* associated with the individual knowledge creator (labeled "I PR" in the table; reach = 1), his or her group (labeled "G PR"; reach = 10), and the sum of individual and group power (labeled "T PR") for each time step in the case of tacit knowledge flow. The fifth column reflects the cumulative power (labeled "TCum PR") in this case; that is, it accumulates *total knowledge power* as the sum of power for all previous time steps.

If knowledge power = 10 signifies disabling an adversary's network attack capability for one hour, for instance, then each ten increments of cumulative knowledge power (TCum PR) would represent an additional hour of disabled capability (i.e., power = 20 → 2 hours' disabled capability, power = 100 → 10 hours' disabled capability, and so forth).

Looking at the first row representing Time 0, one can see that individual knowledge power (I PR) has an arbitrary value of 10. We set the flow time for tacit knowledge arbitrarily at 10 time steps also. We are interested in the relative dynamic behavior and performance of tacit versus explicit flows, so such arbitrary values do not affect the relative dynamics; as noted above, we also examine how sensitive the results are to such arbitrary values. Additionally, because no knowledge flows to the group level have been accomplished at Time 0, the value for group power (G PR) is 0, and the sum (T PR) reflects a contribution from only the individual's knowledge of 10. The cumulative knowledge power (T Cum PR) includes only the knowledge accumulated in this first time step. Continuing with our operationalization above, this signifies disabling an adversary's network attack capability for one hour.

Table 3 Baseline Results for 10 Time Steps

	Tacit KF				Explicit KF			
Time	I PR	G PR	T PR	T Cum PR	I PR	G PR	T PR	E Cum PR
0	10	0	10	10	10	0	10	10
1	10	0	10	20	10	10	20	30
2	10	0	10	30	10	10	20	50
3	10	0	10	40	10	10	20	70
4	10	0	10	50	10	10	20	90
5	10	0	10	60	10	10	20	110
6	10	0	10	70	10	10	20	130
7	10	0	10	80	10	10	20	150
8	10	0	10	90	10	10	20	170
9	10	0	10	100	10	10	20	190
10	10	100	110	210	10	10	20	210

The next time step (Time 1) reflects this same level of knowledge power for the individual (I PR), group (G PR) and total (T PR), with an accumulated level (T Cum PR) of 20 reflecting 10 in Times 0 and 1. Using our operationalization from above, this signifies disabling an adversary's network attack capability for 2 hours; here, the same knowledgeable individual would have applied his or her knowledge across two time periods. He or she would also have spent time working to help others in the group to learn the associated techniques.

Indeed, because ten time steps are required for this individual's tacit knowledge to flow to the group level, the pattern continues until Time 10, at which we see the group knowledge power level increase to 100. This reflects the tacit power level of 10 as it flows across all ten members (i.e., reach = 10) of the group (Power 10 x Reach 10 = 100). The total knowledge power (110) reflects contributions from both individual (10) and group (100) levels of reach here at Time 10, and such contributions more than double the cumulative knowledge power (210) from the previous time step. Cumulative knowledge power = 210 implies that the organization is able to disable an adversary's network attack capability for 21 hours, which is nearly a whole day of elapsed time (e.g., a metaphorical eternity in terms of cyber time). This illustrates the power of tacit knowledge as it flows to reach the group level.

The next four columns reflect the same results for explicit knowledge flows. As above, at Time 0 the individual (I PR = 10), group (G PR = 0), total (T PR = 10) and cumulative (E Cum PR = 10) knowledge power corresponding to explicit flows are identical to those shown for their tacit counterparts; the same knowledge exists at the individual level only, and the individual knowledge power remains at 10. At Time 1, however, the explicit flow pattern diverges from the tacit one. Here, the knowledgeable individual continues to apply his or her knowledge, but he or she also articulates such knowledge in explicit form (e.g., via intranet documents, revised procedures, PowerPoint slides, e-mail messages) and distributes it throughout the organization.

Notice in this case that group knowledge power (G PR = 10) increases to 10 immediately at Time 1. This increases the total (T PR = 20) and cumulative (TCum PR = 30) values correspondingly within a single time period. The other members of the group are not working at the same proficiency level as our knowledgeable individual, but there are ten additional people working at a lower yet non-zero level. Continuing as above, knowledge power = 30 signifies three hours of denied adversary attack capability.

This divergent pattern and the higher knowledge power levels reflect two opposing dynamics: 1) explicit knowledge is flowing much faster (10x) than tacit knowledge is, hence knowledge flows to the group level of reach in only one time step; but 2) explicit knowledge is much less powerful (0.10x) than tacit knowledge is, hence group level knowledge power (Power 1 x Reach 10 = 10) is no higher than the individual's; that is, ten (novice) people in the group work with roughly the same proficiency as one (expert). This kind of novice-to-expert performance variance is very well-established in the expert systems and knowledge management literatures (Nissen, 2006; Turban, Aronson, & Liang, 2005).

The pattern continues, and in this baseline example, one can see that the cumulative knowledge power associated with tacit flows (210) is equal to that of explicit flows (210). As above, this translates to 21 hours of denied adversary capability. Thus, at the end of ten time steps, a decision maker focusing on cumulative knowledge power (and hence organizational performance) would be indifferent between the tacit and explicit knowledge flows in terms of *effectiveness*. In terms of *efficiency*, however, the organization focused on explicit knowledge is paying ten people in the group to accomplish the same result as the lone, knowledgeable individual. We presume that each of such people earn more than 10% of the knowledgeable individual's salary.

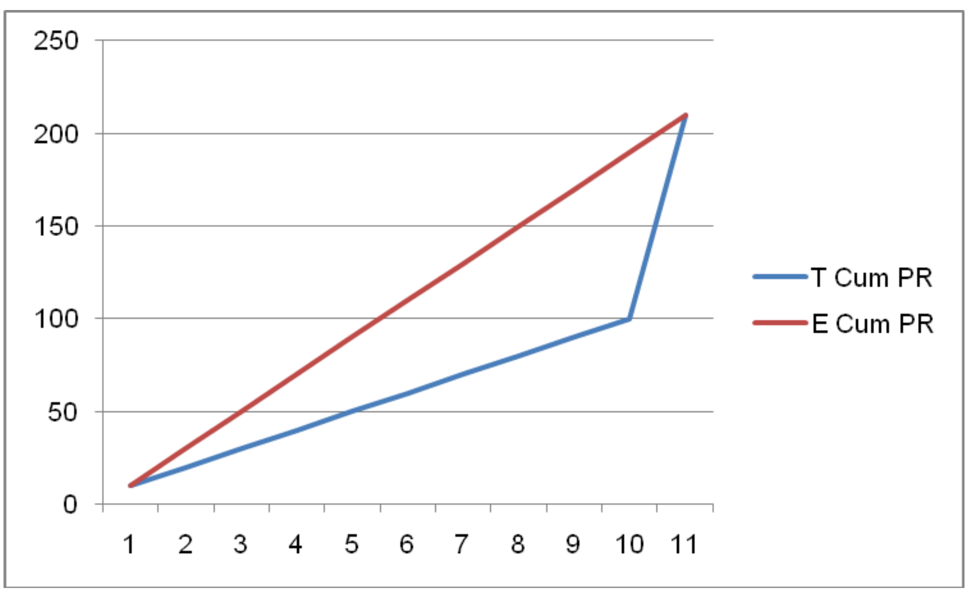

Figure 5 Baseline Cumulative Knowledge Power through Time 10

Despite such equal totals and indifference in terms of efficacy, however, the longitudinal profiles of the two knowledge flows differ qualitatively. As delineated in Figure 5, these results reflect the explicit knowledge power accumulating (labeled "E Cum PR") rapidly and linearly from Time 1 through 10, whereas the accumulation of tacit knowledge power (labeled "T Cum PR") is comparatively slow until a quantum jump at Time 10 (i.e., when tacit knowledge reaches the group level). Thus, where results are needed within the first ten time steps—and the resources are available to have ten people doing the work of one—decision makers would prefer to pursue explicit knowledge flows more than their tacit counterparts. In other words, where quick results are stressed, and resources are available, explicit knowledge flows reflect an advantage over tacit flows.

Table 4 Baseline Results for 20 Time Steps

	Tacit KF				Explicit KF			
Time	I PR	G PR	T PR	T Cum PR	I PR	G PR	T PR	E Cum PR
0	10	0	10	10	10	0	10	10
1	10	0	10	20	10	10	20	30
2	10	0	10	30	10	10	20	50
3	10	0	10	40	10	10	20	70
4	10	0	10	50	10	10	20	90
5	10	0	10	60	10	10	20	110
6	10	0	10	70	10	10	20	130
7	10	0	10	80	10	10	20	150
8	10	0	10	90	10	10	20	170
9	10	0	10	100	10	10	20	190
10	10	100	110	210	10	10	20	210
11	10	100	110	320	10	10	20	230
12	10	100	110	430	10	10	20	250
13	10	100	110	540	10	10	20	270
14	10	100	110	650	10	10	20	290
15	10	100	110	760	10	10	20	310
16	10	100	110	870	10	10	20	330
17	10	100	110	980	10	10	20	350
18	10	100	110	1090	10	10	20	370
19	10	100	110	1200	10	10	20	390
20	10	100	110	1310	10	10	20	410

Alternatively, where results over a longer period of time are stressed more than shorter term results—or where resources are constrained—the decision making preference would switch.

Table 4 summarizes this same simulation across the subsequent ten time steps and reveals how the tacit knowledge power accumulates far beyond the levels attained through explicit flows. Indeed, by Time 20 the cumulative tacit knowledge power (1310) is more than triple the explicit level (410). As above, this translates to 131 versus 41 hours of network attack capability denied to an adversary.

This pattern continues and is delineated in Figure 6. Thus, for any number of time steps beyond ten—where results are not needed until after the first ten time steps—decision makers would prefer to pursue tacit knowledge flows more than their explicit counterparts. In other words, where quick results are not stressed, tacit knowledge flows reflect an advantage over explicit flows, and the longer the time that knowledge flows through the organization, the more dominant that tacit knowledge flows become with respect to their explicit counterparts in terms of efficacy.

Considering efficiency bolsters this result even further, but one could introduce additional factors such as the risk associated with our lone, knowledgeable individual leaving the organization. This basic measurement scheme is broadly extensible and highly generalizable, so incorporation of additional factors such as this is relatively straightforward. To avoid digression, we do not consider efficiency, risk, or other factors further in this paper.

Thus, the dynamic properties and behaviors of our measured tacit and explicit knowledge flows reflect contrasting performance levels and conditions. Explicit knowledge flows—and hence knowledge power that drives performance and supports competitive advantage—accumulate more quickly than tacit flows do; hence explicit knowledge flows should be emphasized where relatively quick results are important to organizational decision makers but high knowledge power accumulation is not. Alternatively, tacit knowledge flows—and hence knowledge power that drives performance and supports competitive advantage—accumulate to higher levels than explicit flows do; hence tacit knowledge flows should be emphasized where relatively quick results are not so important to organizational decision makers but high knowledge power accumulation is.

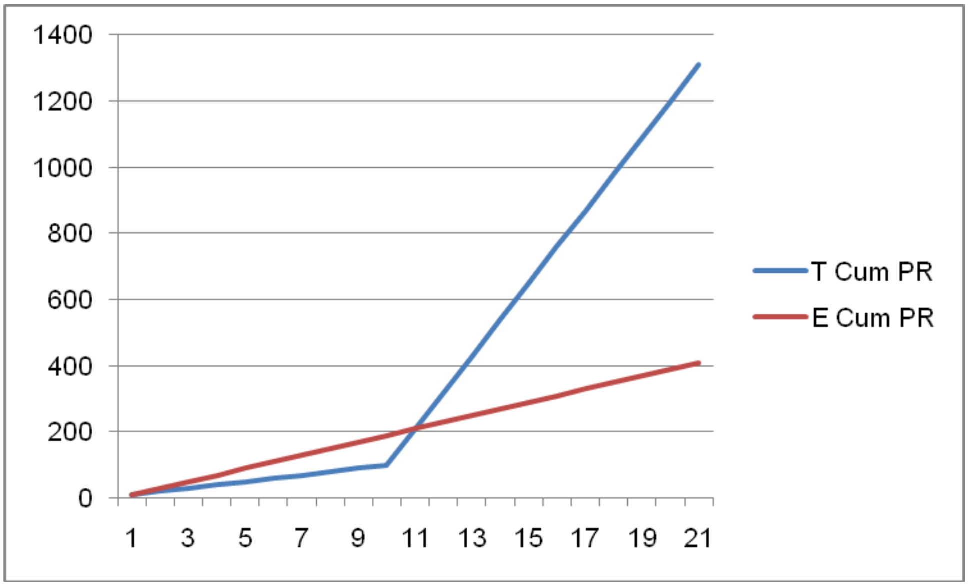

Figure 6 Baseline Cumulative Knowledge Power through Time 20

As we extend this example to knowledge flows reaching the organizational level, the same patterns repeat for each of the ten organizational groups. For instance, say that the people in the group above (call it "Group 1") begin working to share knowledge with a second group (call it "Group 2") at Time 20. The tacit and explicit knowledge flow patterns and corresponding knowledge power accumulation profiles would be identical to those tabulated and delineated above for Group 1. Only the time steps would differ (e.g., Group 2 explicit knowledge would start accumulating at Time 21 instead of Time 1 as for Group 1; Group 2 tacit knowledge would start accumulating at Time 30 instead of Time 10 as for Group 1). The same pattern would extend then for all of the other organizational groups. Because such patterns and profiles repeat for each group, we omit the corresponding tables and figures, which are largely redundant with those for Group 1 above.

2. Knowledge Flow Time Sensitivity Example

Table 5 Knowledge Flow Time Sensitivity Results for 20 Time Steps

	Tacit KF				Explicit KF			
Time	I PR	G PR	T PR	T Cum PR	I PR	G PR	T PR	E Cum PR
0	10	0	10	10	10	0	10	10
1	10	0	10	20	10	10	20	30
2	10	0	10	30	10	10	20	50
3	10	0	10	40	10	10	20	70
4	10	0	10	50	10	10	20	90
5	10	0	10	60	10	10	20	110
6	10	0	10	70	10	10	20	130

7	10	0	10	80	10	10	20	150
8	10	0	10	90	10	10	20	170
9	10	0	10	100	10	10	20	190
10	10	0	10	110	10	10	20	210
11	10	0	10	120	10	10	20	230
12	10	0	10	130	10	10	20	250
13	10	0	10	140	10	10	20	270
14	10	0	10	150	10	10	20	290
15	10	0	10	160	10	10	20	310
16	10	0	10	170	10	10	20	330
17	10	0	10	180	10	10	20	350
18	10	0	10	190	10	10	20	370
19	10	0	10	200	10	10	20	390
20	10	100	110	310	10	10	20	410

To assess the sensitivity of results to the assumptions and arbitrary numerical values used in the baseline example above, here we include an alternate example that reflects a much longer flow time (20 time steps instead of 10) for tacit knowledge; hence in this example tacit knowledge flows 20 times more slowly than explicit knowledge does. This could apply, for instance, to highly technical, context-specific and judgment-oriented knowledge that does not flow quickly.

Table 5 summarizes the simulated results for the initial condition at Time 0 and the subsequent twenty time steps. As expected, group knowledge power does not begin accumulating until Time 20 (G PR = 100; reach = 10), and the cumulative tacit knowledge power (T CUM PR = 310) at this time step is much lower than in the baseline example above; it is considerably lower also than the explicit power is (i.e., 310 vs. 410). Results for the explicit knowledge flows are unchanged from above.

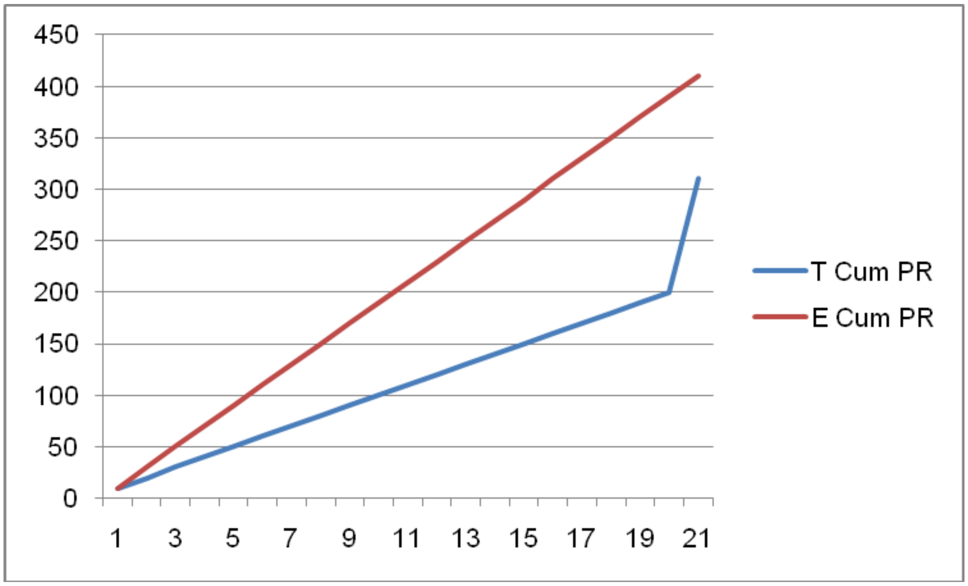

Figure 7 Flow Time Sensitivity Cumulative Knowledge Power

As expected also, the cumulative knowledge power profile delineated in Figure 7 reflects the explicit knowledge flow as dominating its tacit counterpart throughout the first twenty time steps. The tacit flows, however, begin their quantum increase at Time 20, and as above, cumulative knowledge power corresponding to tacit flows will surpass those generated by explicit flows as the time steps continue. Qualitatively, the results are comparable to those in the baseline example above. Only the timing of the quantum, group-level increase in tacit knowledge power (i.e., at Time 20 vs. Time 10) changes. As above, extension to the organizational level of reach represents a repetition of this pattern and is not shown.

3. Knowledge Power Sensitivity Example

To continue assessing the sensitivity of results to the assumptions and arbitrary numerical values used in the baseline example above, here we include an alternate example that reflects a much lower power level (2 instead of 10) for tacit knowledge reaching the group level; hence in this example tacit knowledge carries only 2 times the power at the group level that explicit knowledge does. This could apply, for instance, to less technical, context-specific and judgment-oriented knowledge that does flow quickly. As in the baseline example, ten time steps are required for tacit knowledge to reach the group level; that is, the tacit knowledge flow time in this example is the same (i.e., 10 time steps) as in the baseline example, so only the power level changes.

Table 6 summarizes the simulated results for the initial condition at Time 0 and the subsequent twenty time steps. As with the baseline example, tacit group knowledge power does not begin accumulating until Time 10 (G PR = 20; reach = 10), and the cumulative knowledge power (T CUM PR = 130) at this time step is considerably lower than in the baseline example above. Results for the explicit knowledge flows are unchanged from above. Notice that the cumulative knowledge power corresponding to tacit and explicit flows is very close at Time 20 (i.e., 430 vs. 410).

Table 6 Knowledge Power Sensitivity Results for 20 Time Steps

	Tacit KF				Explicit KF			
Time	I PR	G PR	T PR	T Cum PR	I PR	G PR	T PR	E Cum PR
0	10	0	10	10	10	0	10	10
1	10	0	10	20	10	10	20	30
2	10	0	10	30	10	10	20	50
3	10	0	10	40	10	10	20	70
4	10	0	10	50	10	10	20	90
5	10	0	10	60	10	10	20	110
6	10	0	10	70	10	10	20	130
7	10	0	10	80	10	10	20	150
8	10	0	10	90	10	10	20	170
9	10	0	10	100	10	10	20	190
10	10	20	30	130	10	10	20	210
11	10	20	30	160	10	10	20	230
12	10	20	30	190	10	10	20	250
13	10	20	30	220	10	10	20	270
14	10	20	30	250	10	10	20	290
15	10	20	30	280	10	10	20	310
16	10	20	30	310	10	10	20	330
17	10	20	30	340	10	10	20	350
18	10	20	30	370	10	10	20	370
19	10	20	30	400	10	10	20	390
20	10	20	30	430	10	10	20	410

As expected also, the cumulative knowledge power profile delineated in Figure 8 reflects the explicit knowledge flow as dominating its tacit counterpart throughout the first ten time steps. The tacit flows, however, begin their increase at Time 10, and as above, cumulative knowledge power corresponding to tacit flows surpasses those generated by explicit flows as the time steps continue. Indeed, the two curves cross at Time 18. Qualitatively, the results are comparable to those in the baseline example above. Only the knowledge power level at the quantum, group-level increase in tacit knowledge (i.e., at power level 2 vs. power level 10) changes. As above, extension to the organizational level of reach represents a repetition of this pattern and is not shown.

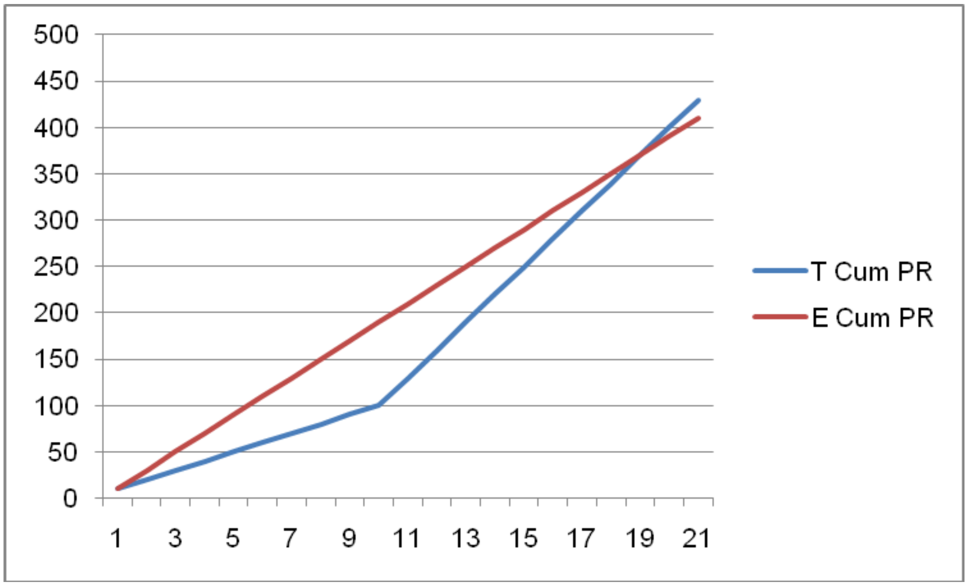

Figure 8 Power Sensitivity Cumulative Knowledge Power

4. Summary of Examples

We could of course include other sensitivities for analysis and comparison, but the two above reflect the most influential assumptions: knowledge flow time and power. Other sensitivities (e.g., the number of people comprising a group, the number of groups comprising an organization, the number of time steps examined) generate knowledge flow patterns and knowledge power profiles that are comparable to and qualitatively the same as those examined above. Hence we understand the key dynamic properties and behaviors of tacit and explicit knowledge flows.

To summarize, explicit knowledge flows can extend the reach of knowledge more quickly than tacit flows can, so group level knowledge and power accumulate more quickly through the former than the latter. Where quick results are important to organizational leaders and managers—and resources are available to have multiple people in a group performing at the same level as a lone, knowledgeable individual—decision makers would emphasize explicit knowledge flows. Alternatively, tacit knowledge flows carry greater power than explicit flows do, so group level knowledge and power accumulate to higher levels over time through the former than the latter. Where high knowledge power levels are important to organizational leaders and managers—and resources are limited in terms of personnel—decision makers would emphasize tacit knowledge flows.

V. CONCLUSION

Knowledge is key to sustainable competitive advantage, but different kinds of knowledge affect competitive advantage differently, and they exhibit qualitatively different dynamic properties and behaviors. This places particular importance on understanding the dynamics of knowledge as it flows from where and when it is to where and when it is needed. Given the increasingly strategic importance of computer networks in terms of achieving, defending and ultimately sustaining competitive advantage, understanding how to manage dynamic knowledge through Cyberspace has become critical to organizational survival. Unfortunately, considerable confusion and uncertainty regarding Cyberspace knowledge management (CyberKM) abound and persist, rendering pursuits of sustainable competitive advantage daunting at best and infeasible in many cases.

The research described in this paper builds upon Knowledge Flow Theory to illustrate a scheme for measuring dynamic knowledge flows in the cyber domain. Emphasizing the dimensions *flow time* and *reach* to characterize the dynamics of knowledge flows, we introduce a set of definitions and assumptions that enable us to measure the dynamic properties and behaviors of knowledge as it flows through the organization. Further, introducing the construct *knowledge power* and linking it to organizational performance and hence competitive advantage in terms of Cyberspace, we build upon the measurement capability above to enable decision makers to assess the relative strengths and weaknesses of alternate approaches to promoting knowledge flows in the cyber domain. This represents a key contribution of the investigation.

For instance, we find generally that explicit knowledge flows can extend the reach of knowledge more quickly than tacit flows can, so group level knowledge and power accumulate more quickly through the former than the latter. Where quick results are important to organizational leaders and managers, and personnel resources permit comparatively inefficient work, decision makers would emphasize explicit knowledge flows. Alternatively, tacit knowledge flows carry greater power than explicit flows do, so group level knowledge and power accumulate to higher levels over time through the former than the latter. Where high knowledge power levels are important to organizational leaders and managers, and personnel resources are constrained, decision makers would emphasize tacit knowledge flows.

As noted above, Through this novel approach to measurement, one can analyze and visualize the relative power, speed and proliferation of both tacit and explicit knowledge through organizations, which enables knowledge leaders, managers and workers to understand the comparative costs and benefits of alternate approaches to and technologies for managing cyber knowledge. This work articulates a clear set of tradeoffs facing decision makers in Cyberspace, and it provides principles-based techniques for making cyber knowledge decisions in a rational and informed manner.

This dynamic knowledge measurement scheme offers a theoretical contribution suitable for academic journals as is, but it also elucidates an exciting path for continued research along these lines. For instance, this investigation suggests that empirical research to measure variables such as *knowledge flow time*, *reach* and *power* for operational organizations in the field would be very useful, particularly where measurements for both tacit and explicit knowledge flows could be obtained. As another instance, we note how linking knowledge power to organizational performance, and in turn to (sustainable) competitive advantage, appears to represent a challenging empirical task; hence empirical work to establish and measure such linkages would be very useful also. As a third instance, we encounter considerable difficulty operationalizing the dimensions *knowledge explicitness* and *life cycle*; hence research to operationalize such dimensions in terms of measurement constructs would be very useful as well.

Further, a wide variety of different organizational processes can be used to promote tacit and explicit knowledge flows. In the present research we analyze two, relatively general processes (e.g., socialization and formalization), but follow-on research to extend this investigation in a manner that can distinguish between the dynamic knowledge flow properties and behaviors corresponding to a variety of diverse processes would likely produce excellent insights and stimulate even more research along these lines.

Additionally and importantly, this work highlights practical application as well through enhanced decision making in the context of harnessing dynamic knowledge for sustainable competitive advantage through Cyberspace. For instance, recall from above how we differentiate *knowledge* from *information, data* and like concepts through its ability to enable action. Because knowledge-based action drives performance, and performance supports competitive advantage, knowledge lies on the critical path for such competitive advantage. Accordingly, the better that one can manage cyber knowledge, the better that one can support network-based competitive advantage. Moreover, we note also how knowledge is inherently dynamic and how dynamic knowledge must be harnessed for competitive advantage. Hence the better that one can manage the dynamics of knowledge, the better that one can sustain competitive advantage over time.

As another instance, we note further how the dynamics of explicit and tacit knowledge flows differ markedly: explicit knowledge flows can extend the reach of knowledge more quickly than tacit flows can, but tacit knowledge flows carry greater power than explicit flows do. One important managerial implication is that organizations may decide to invest first in promoting explicit knowledge flows in order to produce quick results in terms of competitive advantage. However, the diluted power of explicit knowledge limits its efficacy over time, and it can contribute to inefficiencies, so organizations need to invest also in promoting tacit knowledge flows in order to produce sustainable and efficient results in terms of competitive advantage.

Finally, management requires commitment and patience in order to achieve the kinds of knowledge-based competitive advantage and Cyberspace capability discussed in this paper. Commitment to promoting tacit knowledge flows is required, because such flows are relatively slow and narrow; a sustained investment in their promotion is necessary to attain and sustain competitive advantage. Likewise, because considerable time and investment are likely to be necessary for such sustained advantage and creation, patience is critical; management cannot expect to achieve the immediate successes through tacit knowledge flows that are achievable through their explicit counterparts, but the high power of tacit flows will make such patience worthwhile over time.

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